Effects of exposure to high ambient temperature and dietary protein level on sow milk production and performance of piglets

David Renaudeau, Jean Noblet

Effects of exposure to high ambient temperature and dietary protein level on sow milk production and performance of piglets[1]

D. Renaudeau and J. Noblet

Institut National de la Recherche Agronomique, 35590 Saint Gilles, France

ABSTRACT: The effects of high ambient temperature and level of dietary heat increment on sow milk production and piglet performance over a 28-d lactation were determined in 59 multiparous crossbred Large White × Landrace pigs kept at a thermoneutral (20°C) or in a hot (29°C) constant ambient temperature. Experimental diets fed during lactation were a control diet (NP; 17.6% CP) and two low-protein diets obtained by reduction of CP level (LP; 14.2% CP) or both reduction of CP and addition of fat (LPF; 15.2% CP); the NE:ME ratio was 74.3, 75.6, and 75.8% for NP, LP, and LPF diets, respectively. All diets provided 0.82 g of digestible lysine/MJ of NE, and ratios between essential AA and lysine were above recommendations. Creep feed was provided after d 21 of lactation. Reduction of CP level did not influence (*P* > 0.10) milk production, milk composition, or piglet performance. Despite higher nursing frequency (39 vs 34 sucklings per day), milk production decreased (*P* < 0.01) from 10.43 to 7.35 kg/d when temperature increased from 20 to 29°C. At d 14, DM (18.6 vs 18.1%) and energy (4.96 vs 4.75 MJ/kg) contents in milk tended (*P* = 0.09) to be higher in sows kept at 29°C. Over the 28-d lactation, piglet BW gain and BW at weaning decreased (*P* < 0.01) from 272 to 203 g/d and 9.51 to 7.52 kg, respectively, when temperature increased from 20 to 29°C. Daily creep feed intake over the 4th wk of lactation was higher (*P* < 0.01) at 29°C than at 20°C (388 vs 232 g/litter, respectively), which was reflected in a greater increase in BW gain between wk 1 to 3 and wk 4 at the higher temperature (147 vs 130%); BW gain between weaning and d 14 postweaning was higher (*P* < 0.05) for piglets originating from sows kept at 29°C (280 vs 218 g/d). In connection with their lower growth rate, DM (31.2 vs 33.0%), protein (15.5 vs 16.0%), lipid (12.3 vs 13.9%), and energy (8.39 vs 9.09 kJ/g) contents in weaned, slaughtered piglets were lower (*P* < 0.01) at 29 than at 20°C. In conclusion, modification in the CP:NE ratio in order to decrease dietary heat increment did not affect milk production and piglet performance in thermoneutral or hot climatic conditions. Our results confirm the negative effect of high ambient temperatures on milk yield and emphasize the importance of creep feed supply to improve pre- and postweaning growth of piglets in these conditions, especially when weaning occurs after 3 wk of age.

Key Words: Body Composition, Creep Feeding, Heat Stress, Lactation, Piglets, Sows

 J. Anim. Sci. 2001. 79:1540–1548

Introduction

Genetic improvement of the prolificacy of sows during the two last decades has resulted in an indirect increase in milk production. Nowadays, the growth rate of a litter can reach 3 kg/d, which corresponds to an estimated milk yield of about 12 kg /d (Noblet and Etienne, 1989). Under thermoneutral conditions, milk production of a lactating sow depends on lactational ability of the sow (genotype and feed consumption) (Etienne et al., 2000) and nursing demands (litter size, suckling frequency, and piglet body weight) (Auldist and King, 1995; Auldist et al., 2000).

Exposure to high ambient temperature (above 25°C) has been reported to decrease voluntary feed intake and milk production of the sow and, consequently, litter growth rate (Black et al., 1993; Quiniou and Noblet, 1999). In most studies, these effects of high ambient temperature on milk yield could be explained by a reduction of nutrient supply in connection with reduced feed intake. Results of Mullan et al. (1992; cited by Black et al., 1993) and Messias de Braganca et al. (1998) also suggest a direct effect of ambient temperature on milk production. The change in voluntary feed intake at high temperature can be attenuated through

[1]The authors gratefully acknowledge Degussa-Hüls (Germany) and Eurolysine (Paris, France) for their financial support of the experiment, Eurolysine (Paris, France) for measurement of amino acid content in feeds, Institut Technique du Porc (Paris, France) for the grant of D. R., J. Van Milgen for critical evaluation of the manuscript, and P. Bodinier, S. Daniel, S. Dubois, J. Gauthier, and H. Renoult for their technical assistance.

[2]Correspondence: E-mail: noblet@st-gilles.rennes.inra.fr.

Received September 9, 2000.

Accepted February 12, 2001.

using low-heat-increment diets either by addition of fat (Schoenherr et al., 1989; Quiniou et al., 2000) or by reduction of CP concentration (Renaudeau et al., 2001). However, the responses of piglets to variations of diet composition according to ambient temperature are insufficiently described. The aim of the present study was to investigate the effects of a reduction in dietary CP and of fat addition on performance and feeding behavior of lactating sows and on milk production and litter performance at high ambient temperature. Results on lactation performance of sows have been reported by Renaudeau et al. (2001). This paper deals with the effects of high ambient temperature and diet composition on milk production and piglet performance.

Materials and Methods

Experimental Design

Fifty-nine multiparous crossbred Large White × Landrace sows, divided into 11 groups of four to six animals, were used in the experiment. Each group of sows was kept either in thermoneutral (20°C) or hot (29°C) climatically controlled farrowing rooms during a 28-d lactation and the subsequent 14-d postweaning period. The ambient temperature was maintained constant over the day. Sows were randomly allocated to three dietary treatments within each group. The three experimental diets differed in their ratio between NE and ME (i.e., their dietary heat increment). Change of this ratio was obtained by formulating a diet with a standard CP and low fat content (**NP** diet; 17.6% CP and 2.5% fat) and two diets with a reduced CP level not supplemented (**LP** diet; 14.2% CP and 2.6% fat) or supplemented with 4% of vegetable fat (**LPF** diet; 15.5% CP and 6.1% fat). The three diets supplied the same levels of lysine (0.82g digestible lysine/MJ of NE), and levels of digestible essential AA relative to lysine were similar and higher than values recommended by Dourmad et al. (1991). Mineral and vitamin contents met or exceeded the recommendations of INRA (1989). A full description of animal management, housing conditions, and diet compositions has been reported previously (Renaudeau et al., 2001).

Within the first 12 h after birth (d 0), piglets received an injection of 200 mg of iron dextran and were identified by tattooing. The litter size was standardized to 12 pigs by cross fostering within 48 h after birth. When the number of available piglets was too low, piglets from nonexperimental sows were fostered. A heating zone was provided for piglets using infrared lamps and a heating mat. At d 14, piglets received a second iron injection and males were castrated. Creep feed (16.6 MJ of DE/kg, 21.4% CP) was offered to the pigs at 21 d after birth. At d 28 of lactation, litters were weaned and moved to postweaning rooms set at 27°C and provided free access to water and a standard postweaning diet (15.8 MJ of DE/kg, 21.5% CP).

Measurements and Chemical Analysis

Piglets were individually weighed at birth and at d 7, 14, 21, and 28 during the 4-wk lactation. From the 21st day, creep feed was offered and daily consumption by the litter was determined as the difference between the feed offered and the feed refused and wasted. The feed wastage was measured using plastic trays placed under the slats around the creep feed area. Piglets were also weighed 14 d after weaning; feed consumption was not recorded after weaning. Suckling frequency was determined between d 8 and 12 over a 24-h period and only one time during lactation using an infrared camera. During these days, technical interventions were minimal; thus, sows were not disturbed. For technical reasons, it was not possible to measure all sows; in addition, we visually observed that sucklings were generally synchronized within a farrowing room. Consequently, suckling frequency was measured on two sows per group, so that 11 observations were available at each temperature. Our methodology was unable to differentiate successful nursings and nursings without milk ejection.

At d 14, piglets were separated from the dam after suckling. Thirty to 50 min later, the sow was injected with 10 IU of oxytocin (Intervet, Angers, France) in an ear vein and all functional glands were hand-milked to determine milk composition. Using this methodology, a maximum of four sows could be hand-milked per group. The amount of milk collected was close to the estimated milk production during one suckling between d 7 and 14. Samples were immediately stored at −20°C and subsequently analyzed for DM, ash, nitrogen and fat according to AOAC (1990) methods. Lactose content was determined using an enzymatic method (Boehringer Mannheim, ref. 176 303). Energy content was determined using an adiabatic bomb calorimeter after previous freeze-drying of 5 g of milk in small polyethylene bags.

For determination of body composition of piglets at weaning, one piglet was slaughtered after electrical stunning. This piglet had a BW at weaning and to a smaller extent a birth weight that corresponded to the average of the litter. The digestive tract was emptied and piglets were stored in plastic bags in a deep-freezer (−20°C). A total of 58 piglets were used. Frozen piglets were finely ground and homogenized. For each piglet, three aliquots were constituted and freeze-dried: two for determination of DM and one for further chemical analyses. Samples were analyzed for DM, ash, nitrogen, ether extract, and GE.

Calculations and Statistical Analysis

Milk production and composition (energy and nitrogen output) over the first 3 wk were estimated from litter weight gain and litter size (Noblet and Etienne,

Table 1. Effects of ambient temperature and diet composition on performance of piglets and milk production of sows (adjusted means)

	20°C			29°C				
Item	NP[a]	LP[a]	LPF[a]	NP	LP	LPF	RSD[b]	Statistical analysis[c]
No. of sows	10	9	9	11	11	9		
Duration of lactation, d	28.3	28.4	29.0	28.1	27.9	27.9	0.7	T**, G**
Litter size								
At d 1[d]	12.2	12.0	12.4	11.9	11.8	11.8	1.0	G**
At weaning	10.5	10.3	10.5	10.4	10.3	9.5	1.1	G*
Piglet BW, g								
At d 1[d]	1,586	1,552	1,576	1,579	1,631	1,671	179	
At weaning (d 28)	9,450	9,444	9,642	7,391	7,640	7,534	1,014	T**
At d 14 postweaning	12,641	12,310	12,773	11,349	11,527	11,394	1,217	T*, G**
Piglet BW gain, g/d								
Wk 1, 2, and 3	255	250	257	177	188	181	41	T**
Wk 4	328	343	333	274	282	270	50	T**, G*
Total lactation	271	272	274	199	210	200	37	T**
Weaning to d 14 postweaning	228	202	223	286	278	276	45	T**, G**
Milk production (wk 1, 2, and 3), kg/d[e]	10.58	10.18	10.53	7.25	7.62	7.17	2.01	T**, G†

[a]NP: normal-protein diet, LP: low-protein diet; LPF: low-protein/added fat diet.
[b]Residual standard deviation.
[c]From analysis of variance including the effects of ambient temperature (T), diet composition (D), interaction between temperature and diet composition (T × D) and the effect of group of sows within temperature (G). Statistical significance: **$P < 0.01$, * $P < 0.05$, †$P < 0.10$.
[d]After cross fostering.
[e]Calculated over the first 3 wk from litter weight gain and litter size (Noblet and Etienne, 1989).

1989).[3] Because of creep feed consumption after d 21, milk production over the 4th wk of lactation could not be estimated from litter growth. Body composition characteristics of piglets at weaning are linearly related to growth rate during the suckling period (Noblet and Etienne, 1987). Therefore, chemical composition of the litter at weaning is close to the composition of the piglet whose BW gain is comparable to the mean BW of all littermates. Chemical composition of empty body weight (**EBW**) gain from birth to weaning was calculated assuming that DM, nitrogen, ash, lipid and energy contents at birth were 19, 1.8, 3.5, 1.2% and 3.60 kJ/g, respectively (Noblet and Etienne, 1987).

The data were subjected to analysis of variance (PROC GLM, SAS, Inst. Inc., Cary, NC), including the effect of ambient temperature, diet composition and their interaction. The effect of group of sows was tested within the effect of ambient temperature. The effect of age of piglet (days or weeks) on piglet BW or BW gain was analyzed according to a multifactorial, split-plot analysis of variance that took into account the effects of temperature, diet, and the interactions between these main effects. The effect of stage of lactation on creep feed intake was analyzed as a main effect (PROC REPEATED; SAS, Inst. Inc.). Covariance analyses were also used to analyze body composition data.

Results

The number of pigs per litter at farrowing, on d 1 (i.e., after cross-fostering), and at weaning was not different ($P > 0.10$) among temperatures and dietary CP levels (Table 1). The average birth weight was 1,602 g and did not differ ($P > 0.10$) between treatment groups. Dietary treatments did not affect ($P > 0.10$) piglet growth rate during lactation. Compared to 20°C, exposure to 29°C depressed ($P < 0.001$) piglet BW gain (182 vs 254 g/d) and daily milk yield (7.35 vs 10.43 kg/d) over the first 3 wk of lactation. The difference between both temperatures was attenuated over the 4th wk of lactation (276 vs 335 g/d, $P < 0.01$). Consequently, mean BW of piglets at weaning was higher ($P < 0.01$) at 20°C than at 29°C (9,512 vs 7,539 g). The effect of temperature on BW gain occurred during the whole lactation period; at d 7, piglet BW was already affected (Figure 1a). Piglet BW gain increased ($P < 0.001$) between wk 1 and 2 (110 and 68 g/d) and between wk 3 and 4 (37 and 86 g/d) at 20 and 29°C, respectively (Figure 1b). Between wk 2 and 3, piglet BW gain decreased at 29°C (–25 g/d, $P = 0.03$), whereas it reached a plateau at 20°C. Over the 2-wk postweaning period, piglet BW gain was higher ($P < 0.001$) for piglets that had been reared prior to weaning at 29 rather than at 20°C (280 vs 218 g/d). However, average BW at 14 d after weaning remained approximately 1 kg higher for piglets from sows reared at 20°C (Figure 1a).

Suckling interval, measured at 8 to 12 d of lactation, was lower ($P < 0.05$) at 29 than at 20°C (37.0 vs 42.4 min) and was not affected ($P > 0.10$) by diet composition (Table 2). Distribution of suckling frequency among diets was three, four, and four sows at 20°C and four, four, and three sows at 29°C for NP, LP, and LPF diets, respectively. Mean suckling interval was similar ($P > 0.10$) during daytime and night (41.2 vs 39.1 min). As a consequence, the number of daily sucklings was

[3]Milk yield (g/d) = 2.5 (± 0.26) × ADG ($g \cdot d^{-1} \cdot litter^{-1}$) + 80.2 (± 7.8) × birth BW (kg/litter) + 7 × no. of piglets, $R^2 = 0.91$.

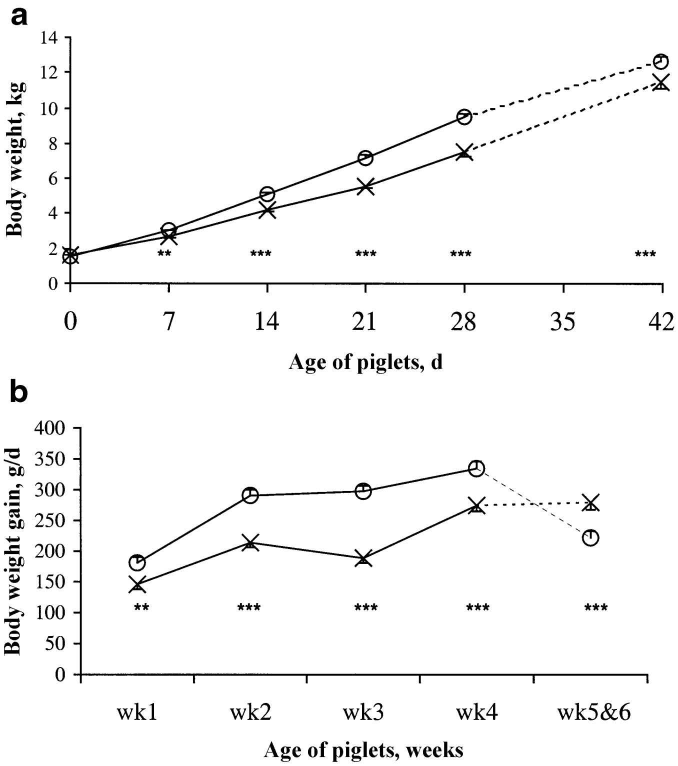

Figure 1. (a) Effect of ambient temperature (x = 29°C, ○ = 20°C) on piglet BW during lactation and the postweaning period (means ± SE); ***P < 0.001, **P < 0.01. (b) Effect of ambient temperature (x = 29°C, ○ = 20°C) on piglet BW gain during lactation and the postweaning period. (means ± SE); ***P < 0.001, **P < 0.01. Based on data of Renaudeau and Noblet (2001).

higher at 29 than at 20°C (39 vs 34). Combined effects of lower milk production and higher number of sucklings at 29°C resulted in a marked (P < 0.01) reduction of milk production per suckling (20 vs 30 g/piglet).

Daily consumption of solid creep feed during the 4th wk of lactation was lower (P < 0.01) for litters at 20 than for those at 29°C (232 vs 388 g/d) (Table 3). It also increased steadily over this week, and the variation was more accentuated at 29 than at 20°C (P < 0.01) (Figure 2). In addition, the initiation of creep feed consumption was quicker (P < 0.05) at 29 than at 20°C; creep feed intake was different from zero (P < 0.05) after d 26 at 20°C and after d 23 at 29°C. Moreover, there was a linear relationship between litter BW gain (g/d) change between wk 4 and 3 of lactation and creep feed intake (g/d): for each additional gram of creep feed, the litter BW gain increased by about 2 g (Figure 3).

Milk composition was not affected (P > 0.10) by diet composition (Table 4). Exposure to 29°C tended (P < 0.10) to increase DM, ash, and energy contents of milk but did not affect (P > 0.10) the three major constituents of milk (protein, lactose, and fat).

Results on body composition of piglets at weaning are presented in Table 5. One piglet from a sow in treatment NP at 29°C was not slaughtered at weaning. Empty digestive tract as a percentage of EBW at weaning increased at 29°C (6.8 vs 5.8% at 20°C). Dry matter, protein, lipid, and energy contents were lower (P < 0.01) in piglets suckling sows kept at 29°C than in those kept at 20°C, whereas ash content was unaffected (P > 0.1). The DM and energy contents in piglets at weaning were higher (P < 0.05) for those fed the LP diet than for those fed the NP or LPF diets without any interactions with ambient temperature. The BW at birth affected BW at weaning (P < 0.01) and lipid (P < 0.05) and energy contents (P < 0.05). According to the data in Table 5 and apart from ash content, chemical composition of weight gain was also affected (P < 0.10) by ambient temperature. Compared to 20°C, DM, protein, lipid, and consequently energy contents were reduced at 29°C (34.6 vs 36.0, 16.6 vs 17.0, 15.4 vs 16.6%, and 9.72 vs 10.24 kJ/g, respectively). As indicated in Table 6, differences in body composition at weaning between temperatures were mainly due to differences in piglet BW gain and BW at birth. When adjusted for similar initial BW and piglet BW gain, the effect of temperature on body composition at weaning was markedly attenuated (P = 0.10).

Discussion

Piglet Growth Rate and Milk Production at High Ambient Temperature

At thermoneutrality, piglet BW gain was higher than that reported by Johnston et al. (1999) in mixed-parity sows (272 vs 242 g/d, respectively); in their study, piglets had no access to creep feed. However, our result is rather similar to piglet BW gain obtained by Quiniou et al. (2000) with hyperprolific, primiparous sows at 20°C (265 g/d). Average daily gain of

Table 2. Effects of ambient temperature on suckling characteristics (adjusted means; unsuccessful sucklings are included)

Item	Temperature °C 20	29	RSD[a]	Statistical analysis[b]
No. of sows	11	11		
Mean lactation stage, d	9.2	8.8	1.1	
No. of piglets per sow[c]	10.4	11.0	1.3	
No. of sucklings per day	34.2	39.2	3.2	T*
Suckling interval, min	42.4	37.0	3.6	T*
Milk production, kg/d[d]	10.72	8.33	2.18	T*
Milk production per suckling[cd]				
g/litter	313	215	70	T*
g/piglet	30	20	6	T**

[a]Residual standard deviation.
[b]From analysis of variance including the effects of ambient temperature (T). Statistical significance: **P < 0.01, *P < 0.05
[c]Between d 7 and 14.
[d]Milk production was calculated from litter gain and litter size between d 7 and 14 (Noblet and Etienne, 1989).

Table 3. Effects of ambient temperature and diet composition on creep feed consumption and performance of piglets over the 4th wk of lactation (adjusted means)

Item	20°C			29°C			RSD[b]	Statistical analysis[c]
	NP[a]	LP[a]	LPF[a]	NP	LP	LPF		
No. of sows	10	9	9	11	11	9		
No. of piglets per sow	10.5	10.3	10.5	10.4	10.3	9.5	1.3	G**
Litter BW gain								
g/d	3,436	3,513	3,511	2,843	2,922	2,605	607	T**, G**
% of Litter BW gain during wk 1, 2, 3	128	136	129	154	149	138	30	T*, G†
Daily creep feed intake								
g/piglet	25	28	16	44	37	33	20	T**, G**
g/litter	254	272	171	456	383	325	200	T**, G**

[a]NP: normal-protein diet; LP: low-protein diet; LPF: low-protein/added-fat diet.
[b]Residual standard deviation.
[c]From analysis of variance including the effects of ambient temperature (T), and the effect of group of sows within temperature (G). Statistical significance: ** $P < 0.01$, * $P < 0.05$, † $P < 0.10$.

piglets was reduced at 29°C (i.e., 203 g/d), in agreement with the previous results of Black et al. (1993) and Quiniou and Noblet (1999). In hot conditions, decrease of piglet BW gain (–72 g/d) over the first 3 wk of lactation is associated with a decrease in estimated milk production of 3.08 kg/d during the same period. It has been hypothesized that a decrease in nursing demand and (or) decrease in the ability of sows to produce milk could explain the reduction of milk yield in hot conditions.

In thermoneutral conditions, suckling interval was comparable to the values of Prunier et al. (1997) and Quiniou and Noblet (1999), measured at the same stage of lactation (39 to 44 min, respectively vs 43 min in present study). Our study indicates that the suckling interval decreased at 29°C. The results of Špinka et al. (1997) indicated an increase in milk production of about 21% when suckling interval was divided by two (70 vs 35 min). Our results and those of Quiniou and Noblet (1999) suggest that exposure to hot climatic conditions is associated with increased nursing demand and therefore an attempt of the piglets to attenuate the effect of high temperature on milk yield. This observation is consistent with the higher milk replacer intake in piglets during the warm season than during the cool season (Azain et al., 1996).

The uptake of nutrients by the mammary gland depends on the blood flow and the nutritional status of the sow, which affect arterial-venous differences (Dourmad et al., 2000). Nutrients for milk production come from food and body reserves. As shown in several studies, moderate feed restriction during lactation does not induce a reduction in litter growth, which means that milk production is maintained at the expense of protein and fat body reserves of the sow (Noblet at al., 1998). Energy restriction would affect milk production and litter growth in severely depleted sows (King and Williams, 1984). Although sows kept at 29°C lost more BW than at 20°C (i.e., 34 vs 16 kg; Renaudeau et al., 2001), this loss remained moderate and the level of body reserves could not be considered as a factor markedly affecting milk production. Messias

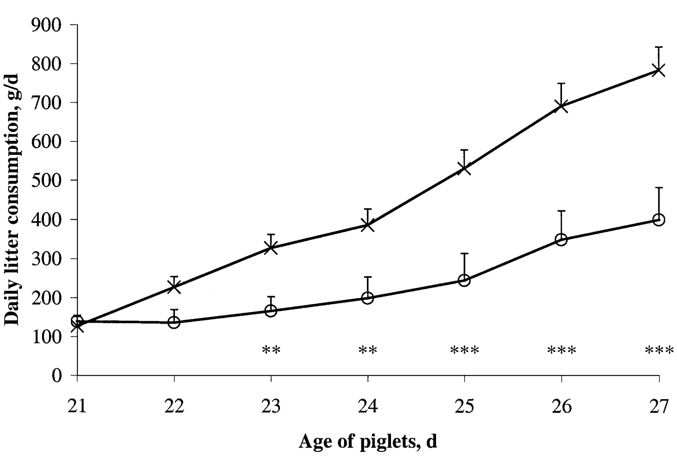

Figure 2. Litter daily creep feed intake (g/d) between d 21 and weaning (x = 29°C, ○ = 20°C) (mean ± SE), *** $P < 0.001$, ** $P < 0.01$. Based on data of Renaudeau and Noblet (2001).

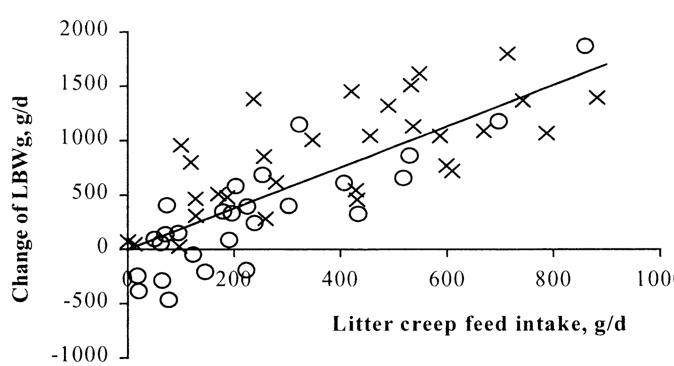

Figure 3. Relationship between litter creep feed intake during the 4th wk of lactation (g/d, x) and the difference in litter BW gain (LBWg; g/d, y) between wk 3 and 4 (y = 1.9 (± 0.2) x; $R^2 = 0.62$, RSD = 361) (x = 29°C, ○ = 20°C). Based on data of Renaudeau and Noblet (2001).

Table 4. Effects of ambient temperature and diet composition on milk composition[a] (adjusted means)

	20°C			29°C				
Item	NP[b]	LP[b]	LPF[b]	NP	LP	LPF	RSD[c]	Stastical analysis[d]
No. of sows	7	6	8	9	10	8		
Milk composition (as is)								
Dry matter, %	18.3	17.8	18.1	18.6	18.5	18.8	1.0	T†, G*
Proteins (N × 6.38), %	5.0	4.9	5.1	5.2	5.0	5.2	0.4	
Ash, %	0.72	0.73	0.75	0.79	0.75	0.78	0.05	T†
Lactose, %	5.2	5.2	5.2	5.2	5.2	5.1	0.2	
Lipids, %	7.1	6.7	6.9	7.3	7.4	7.5	1.0	G*
Energy, kJ/kg	4,862	4,665	4,735	4,942	4,924	5,028	399	T†, G†

[a]Milk collected at d 14.
[b]NP: normal-protein diet; LP: low-protein diet; LPF: low-protein/added-fat diet.
[c]Residual standard deviation.
[d]From analysis of variance including the effects of ambient temperature (T), and the effect of group of sows within temperature (G). Statistical significance: *$P < 0.05$, †$P < 0.10$.

de Braganca et al. (1998) compared lactational performance of primiparous sows kept at 20 or 30°C and given ad libitum access to feed and sows kept at 20°C but fed according to the ad libitum intake recorded at 30°C. In agreement with results of Noblet and Etienne (1986), feed restriction at 20°C did not affect litter growth, so restricted sows mobilized their body reserves to a large extent. However, sows fed similarly but housed at 30°C had lighter piglets. These results suggest a direct effect of elevated ambient temperature on mobilization of body reserves and(or) milk production. Messias de Braganca et al. (1998) reported a reduction of cortisol blood concentration in fed sows at 30°C; this hormone stimulates the mobilization of body reserves (Baidoo et al., 1992). Second, Black et al. (1993) suggested a redistribution of blood flow from the mammary gland to the skin to improve conductive heat loss, which would result in a decrease of nutrients available for milk synthesis. According to results for the lactating cow (Lough et al., 1990) and preliminary results for lactating sows (D. Renaudeau et al., unpublished data), the effect of thermal stress on arterial mammary blood flow would be mediated by the reduction of feed intake and(or) mobilization of body reserves rather than by the thermal stress per se.

Piglet Creep Feed Consumption

As reviewed by Pluske et al. (1995), creep feed intake is generally low (30 g vs 23 g per piglet per day in our study). In hot conditions, creep feed consumption was increased (15 g·piglet^{-1}·d^{-1}), in accordance with results of Quiniou et al. (2000) (6 g·piglet^{-1}·d^{-1} between 20 and 26°C). Similarly, Azain et al. (1996) provided piglets with milk substitute and observed a higher daily milk replacer intake and a greater benefit on piglet BW gain during the warm season (120 g/piglet) than during the cool season (50 g·piglet·d). From the linear relationship between litter BW gain change from wk 3 to 4 and creep feed intake, it can be estimated that each gram of increase of daily creep feed intake resulted in a 2-g increase of litter BW gain. In fact, sow milk is deficient in protein relative to its energy content (Noblet and Etienne, 1987; Williams, 1995); compared to milk, the protein:energy ratio is higher in creep feed (or in milk substitute) (12.4 vs 10.8 g/MJ of GE in the present study). The high marginal efficiency of creep feed for BW gain in suckling piglets would then be due to a marked improvement in protein (and water) deposition at the expense of fat deposition in connection with the higher protein:energy ratio in feed intake (i.e., milk + creep feed). The better development of the digestive tract in weaned piglets at 29°C is consistent with this higher creep feed intake. In addition, the reduced piglet BW gain in the 2 wk following weaning was attenuated for piglets from sows kept at 29°C during lactation. These results support the concept that a high creep feed intake during the suckling period attenuates the weaning stress and is favorable to rapid and higher feed intakes during the postweaning period.

Milk and Piglets Chemical Composition

In agreement with Schoenherr et al. (1989), our results suggest increased DM and energy contents of milk in sows exposed to hot climatic conditions. Similar results were obtained at thermoneutrality when dietary energy supply was reduced and mobilization of body fat reserves was accentuated (Noblet and Etienne, 1986). The combination of both groups of results would indicate that moderate changes in milk composition when sows are exposed to high ambient temperature are related to the more intense mobilization of body reserves.

Composition of weaned piglets was close to the results of Everts and Dekker (1994) in piglets weaned at 25 d without access to creep feed but with comparable growth performance (280 g/d) (32, 15, and 14%, and 9.0 kJ/g, respectively, for DM, protein, lipid, and energy contents). However fat, protein, and energy contents were higher than those reported by Noblet and Etienne (1987) in piglets weaned at 21 d and with a slower growth rate. In fact, chemical composition of weaned

Table 5. Effects of ambient temperature and diet composition on chemical composition of piglets at weaning (adjusted means)

Item	20°C			29°C				
	NP[a]	LP[a]	LPF[a]	NP	LP	LPF	RSD[b]	Statistical analysis[c]
No. of piglets[d]	10	9	9	10	11	9		
BW at birth, kg	1.60	1.65	1.67	1.65	1.56	1.52	0.27	
BW at weaning, kg	9.77	9.86	9.47	7.44	7.56	7.54	1.00	T**, BWi**
EBW at weaning, % BW[e]	97.4	97.8	96.6	96.3	97.0	96.9	1.1	T†
Empty digestive tract, % EBW[e]	5.7	5.2	6.5	6.8	6.5	7.0	0.9	T**
Chemical composition of EBW at weaning[e]								
Dry matter, %	32.7	33.7	33.0	30.5	31.6	31.2	1.5	T**, D*, G**
Protein, %	15.9	16.3	15.8	15.6	15.5	15.5	0.5	T**, G**
Lipid, %	13.6	14.5	13.8	11.5	12.8	12.3	1.6	T**, G*, BWi**
Ash, %	2.9	3.0	3.0	3.0	3.1	3.1	0.2	
Energy, kJ/g	8.98	9.33	9.02	8.12	8.61	8.37	0.58	T**, D*, G*, BWi**
Chemical composition of EBW gain[ef]								
Dry matter, %	35.6	36.6	35.9	33.9	35.2	34.6	1.8	T**, G**
Protein, %	16.9	17.3	16.7	16.8	16.6	16.6	0.7	T†, G*
Lipid, %	16.2	17.1	16.5	14.5	16.1	15.5	1.9	T*, G*
Ash, %	2.8	2.9	2.9	2.8	3.0	3.0	0.2	
Energy, kJ/g	10.12	10.48	10.16	9.43	10.02	9.69	0.72	T**, G*

[a]NP: normal-protein diet; LP: low-protein diet; LPF: low-protein/added-fat diet.
[b]Residual standard deviation.
[c]From analysis of variance including the effects of ambient temperature (T), diet composition (D), the effect of group of sows within temperature (G), and the effect of body weight at birth (BWi) as a covariate. Statistical significance: **$P < 0.01$, *$P < 0.05$, †$P < 0.1$.
[d]One representative piglet slaughtered per litter, except for one sow (treatment NP at 29°C).
[e]Empty body weight.
[f]Between birth and weaning; it is assumed that dry matter, protein, lipids, ash, and energy content at birth were 19.0%, 1.84%, 1.2%, 3.5%, and 3.6 kJ/g, respectively (Noblet and Etienne, 1986).

piglets is correlated to piglet initial BW and BW gain. Our results suggest that the lipid content and, consequently, the DM and energy contents were affected by ambient temperature via an effect on milk production. Furthermore, at 29°C, the increase of energy concentration in milk without change in its protein content resulted in a decrease of the rate of protein deposition, which suggests that the effect of high ambient temperature on protein content of the weaned piglet would also be mediated by a change in milk composition.

Interaction Between Dietary CP and Ambient Temperature on Performance of Piglets

In agreement with results of Dourmad et al. (1998) in primiparous sows and Touchette et al. (1998) in mixed-parity sows, our data suggest that the reduction of CP level, but with constant ratios between essential AA and energy, does not affect litter BW gain or milk composition under thermoneutral climatic conditions. Reduction in CP level without compensation for essential AA (King et al., 1993; Sauber et al., 1998) or with incomplete compensation (Johnston et al., 1999) deteriorates milk production and litter performance. This suggests that a reduction of the dietary CP level by 3 to 4% combined with supplementation of essential AA can maintain litter performance. Moreover, in agreement with NRC (1998) requirements (i.e., 85%), a valine:lysine ratio equal to 0.82 in our low-CP diets (0.85 in the control diet) had no detrimental effect on litter growth rate. This is in contrast to findings of

Table 6: Effect of ambient temperature on chemical composition of empty body weight in weaned piglets

Chemical composition	Temperature, °C		Slope for adjustment			
	20	29	pBWg	BWi	RSD[a]	Statistical analysis[b]
Dry matter, %	32.64	31.53	15.02	–2.83	1.71	T†, pBWg*, BWi**
Protein, %	15.95	15.59	NS	NS	0.58	
Lipid, %	13.59	12.56	12.73	–3.34	1.75	PBWg*, BWi*
Ash, %	2.99	3.03	NS	NS	0.16	
Energy, kJ/g	8.93	8.53	5.81	–1.20	0.65	T†, pBWg*, BWi**

[a]Residual standard deviation.
[b]Adjusted means from covariance analysis with ambient temperature (T) and piglet body weight gain (pBWg, kg/d) and body weight at birth (BWi, kg) as covariates. Statistical significance: **$P < 0.01$, *$P < 0.05$, †$P < 0.10$; NS, non-significant.

Richert et al. (1996), who reported a value of 128% to maximize litter growth rate.

Reduction of dietary CP level maintained litter BW gain in sows kept at 29°C, whereas the daily NE intake was increased by 7.5 MJ/d (Renaudeau et al., 2001). At 29°C, Johnston et al. (1999) showed no change in litter BW gain (60 g/d) when dietary CP level decreased from 16.7 to 13.3%, which is consistent with results of the present study when NP and LP diets are compared. Adding fat (without reduction of CP content) in the lactating sow diet usually increases litter BW gain via an increase of daily milk energy output, particularly in a hot environment (Schoenherr et al., 1989; Christon et al., 1999; Quiniou et al., 2000). The effects of adding fat associated with a reduction of CP level are less clear; however, it does not seem to influence milk production or composition or consequent litter BW gain. In hot conditions, the absence of effects could be explained by the nature of added fat (vegetable vs animal) and(or) the lower rate of fat incorporation in sows' diets (i.e., 4%) compared to higher levels (10%) in studies of Schoenherr et al. (1989) and Christon et al. (1999).

Implications

The present results indicate that the detrimental effects of high ambient temperature on milk production and performances of piglets cannot be attenuated by manipulation of the composition of the sow's diet. This means that in hot conditions diets low in crude protein benefit the sow more than the litter. Whatever the ambient temperature, similar performance of the litter is obtained with conventional diets and low-crude-protein diets supplemented with amino acids. For a 28-d lactation period, this study also demonstrated the importance of creep feed intake; this can markedly attenuate the consequences of heat exposure of sows on pre- and postweaning performance of the litter.

Literature Cited

AOAC. 1990. Official Methods of Analysis. 15 Ed. Assoc. of Official Analytical Chemists, Washington, DC.

Auldist, D. E., D. Carlson, L. Morrish, C. Wakeford, and R. H. King. 2000. The influence of suckling interval on milk production of sows. J. Anim. Sci. 78:2026–2031.

Auldist, D. E., and R. H. King. 1995. Piglets' role in determining milk production in the sow. In: APSA Committee (ed.) pp 114–118. Australasian Pig Science Assoc., Animal Research Institute, Werribee, Australia.

Azain, M. J., T. Tomkins, J. S. Sowinski, R. A. Arentson, and D. E. Jewell. 1996. Effect of supplemental pig milk replacer on litter performance: Seasonal variation in response. J. Anim. Sci. 74:2195–2202.

Baidoo, S. K., E. S. Lythgoe, R. N. Kirkwood, F. X. Aherne, and G. R. Foxcroft. 1992. Effect of lactation feed intake on endocrine status and metabolite levels in sows. Can. J. Anim. Sci. 72:799–807.

Black, J. L., B. P. Mullan, M. L. Lorschy, and L. R. Giles. 1993. Lactation in the sow during heat stress. Livest. Prod. Sci. 35:153–170.

Christon, R., G. Saminadin, H. Lionet, and B. Racon. 1999. Dietary fat and climate alter food intake, performance of lactating sows and their litter and fatty acid composition of milk. Anim. Sci. 69:353–365.

Dourmad, J. Y., M. Etienne, and J. Noblet. 1991. Contribution à l'étude des besoins en acides aminés de la truie en lactation. J. Rech. Porcine Fr. 23:61–68.

Dourmad, J. D., J. J. Matte, Y. Lebreton, and M. L. Fontin. 2000. Influence du repas sur l'utilisation des nutriments et des vitamines par la mamelle, chez la truie en lactation. J. Rech. Porcine Fr. 32:265–273.

Dourmad, J. Y., J. Noblet, and M. Etienne. 1998. Effect of protein and lysine supply on performance, nitrogen balance, and body composition changes of sows during lactation. J. Anim. Sci. 76:542–550.

Etienne, M., C. Legault, J. D. Dourmad, and J. Noblet. 2000. Production laitière de la truie: Estimation, composition, facteurs de variations. J. Rech. Porcine Fr. 32:253–264.

Everts, H., and R. A. Dekker. 1994. Effect of nitrogen supply on nitrogen and energy metabolism in lactating sows. Anim. Prod. 59:445–454.

INRA. 1989. L'alimentation des animaux monogastriques. Institut National de la Recherche Agronomique, Paris, France.

Johnston, L. J., M. Ellis, G. W. Libal, V. B. Mayrose, W. C. Weldon, and NRC-89 Committee on Swine Management. 1999. Effect of room temperature and dietary amino acid concentration on performance of lactating sows. J. Anim. Sci. 77:1638–1644.

King, R. H., M. S. Toner, H. Dove, C. S. Atwood, and W. G. Brown. 1993. The Response of First-Litter sows to Dietary Protein Level During lactation. J. Anim. Sci. 71:2457–2463.

King, R. H., and I. H. Williams. 1984. The effect of nutrition on the reproductive performance of first-litter sows. 1-Feeding level during lactation, and between weaning and mating. Anim. Prod. 38:241–247.

Lough, D. S., D. L. Beede, and C. J. Wilcox. 1990. Effects of feed intake and thermal stress on mammary blood flow and other physiological measurements in lactating dairy cows. J. Dairy Sci. 73:325–332.

Messias de Braganca, M., A. M. Mounier, and A. Prunier. 1998. Does feed restriction mimic the effects of increased ambient temperature in lactating sows? J. Anim. Sci 76:2017–2024.

Mullan, B. P., W. Brown, and M. Kerr. 1992. The response to the lactating sow to ambient temperature. Proc. Nutr. Soc. Aust. 17:215 (Abstr.).

Noblet, J., and M. Etienne. 1986. Effect of energy level in lactating sows on yield and composition of milk and nutrient balance of piglets. J. Anim. Sci. 63:1888–1896.

Noblet, J., and M. Etienne. 1987. Body composition, metabolic rate and utilization of milk nutrients in suckling piglets. Reprod. Nutr. Dev. 27:829–839.

Noblet, J., and M. Etienne. 1989. Estimation of sow milk nutrient output. J. Anim. Sci. 67:3352–3359.

Noblet, J., M. Etienne, and J. Y. Dourmad. 1998. Energetic efficiency of milk production. In: M. W. A. Verstegen, P. J. Moughan, and J. W. Schrama (ed.) The Lactating Sow. pp 113–130. Wageningen Pers, Wageningen, The Netherlands.

NRC. 1998. Nutrient Requirements of Swine; 10th ed. National Academy Press, Washington, DC.

Pluske, J. R., I. H. Williams, and F. X. Aherne. 1995. Nutrition of the neonatal pig. In: M. A. Varley (ed.) The Neonatal Pig: Development and Survival. pp 187–235.CAB International, Wallingford, U.K.

Prunier, A., M. Messias de Braganĉa, and J. Le Dividich. 1997. Influence of high ambient temperature on performance of reproductive sows. Livest. Prod. Sci. 45:103–110.

Quiniou, N., D. Gaudré, S. Rapp, and D. Guillou. 2000. Influence de la température ambiante et de la concentration en nutriments de l'aliment sur les performances de lactation de la truie primipare. J. Rech. Porcine Fr. 32:275–282.

Quiniou, N., and J. Noblet. 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. J. Anim. Sci. 77:2124–2134.

Renaudeau, D., N. Quiniou, and J. Noblet. 2001. Effects of exposure to high ambient temperature and dietary protein level on performance of multiparous lactating sows. J. Anim. Sci. 79:1240–1249.

Richert, B. T., M. D. Tokach, R. D. Goodband, J. L. Nelssen, J. E. Pettigrew, R. D. Walker, and L. J. Johnston. 1996. Valine requirement of the high-producing lactating sow. J. Anim. Sci. 74:1307–1313.

Sauber, T. E., T. S. Stahly, N. H. Williams, and R. C. Ewan. 1998. Effect of lean growth genotype and dietary amino acid regimen on the lactational performance of sows. J. Anim. Sci. 76:1098–1111.

Schoenherr, W. B., T. S. Stahly, and G. L. Cromwell. 1989. The effects of dietary fat or fiber addition on yield and composition of milk from sows housed in a warm or hot environment. J. Anim. Sci. 67:482–495.

Špinka, M., G. Illmann, B. Algers, and Z. Štětková. 1997. The role of nursing frequency in milk production in domestic pigs. J. Anim. Sci. 75:1223–1228.

Touchette, K. J., G. L. Allee, M. D. Newcomb, and R. D. Boyd. 1998. The use of synthetic lysine in the diet of lactating sows. J. Anim. Sci 76:1437–1442.

Williams, I. H. 1995. Sow's milk as major nutrient source before weaning. In: APSA Committee (ed.) pp 107–113. Australasian Pig Science Assoc., Animal Research Institute, Werribee, Australia.